Temperature Dependent Optoelectronic Characterization of III-V Laser Dies on Silicon

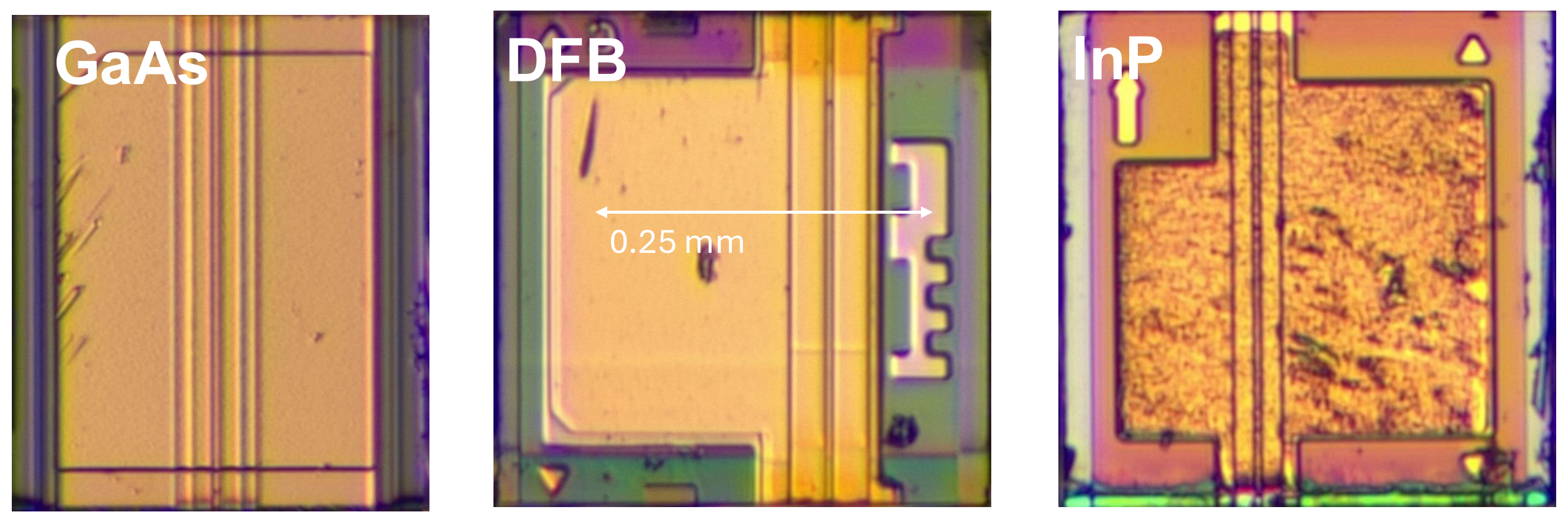
Braden Boucher[1], Dr. Elif Demirbas[1]

Physics, Photonics and Optical Engineering Department, Bridgewater State University

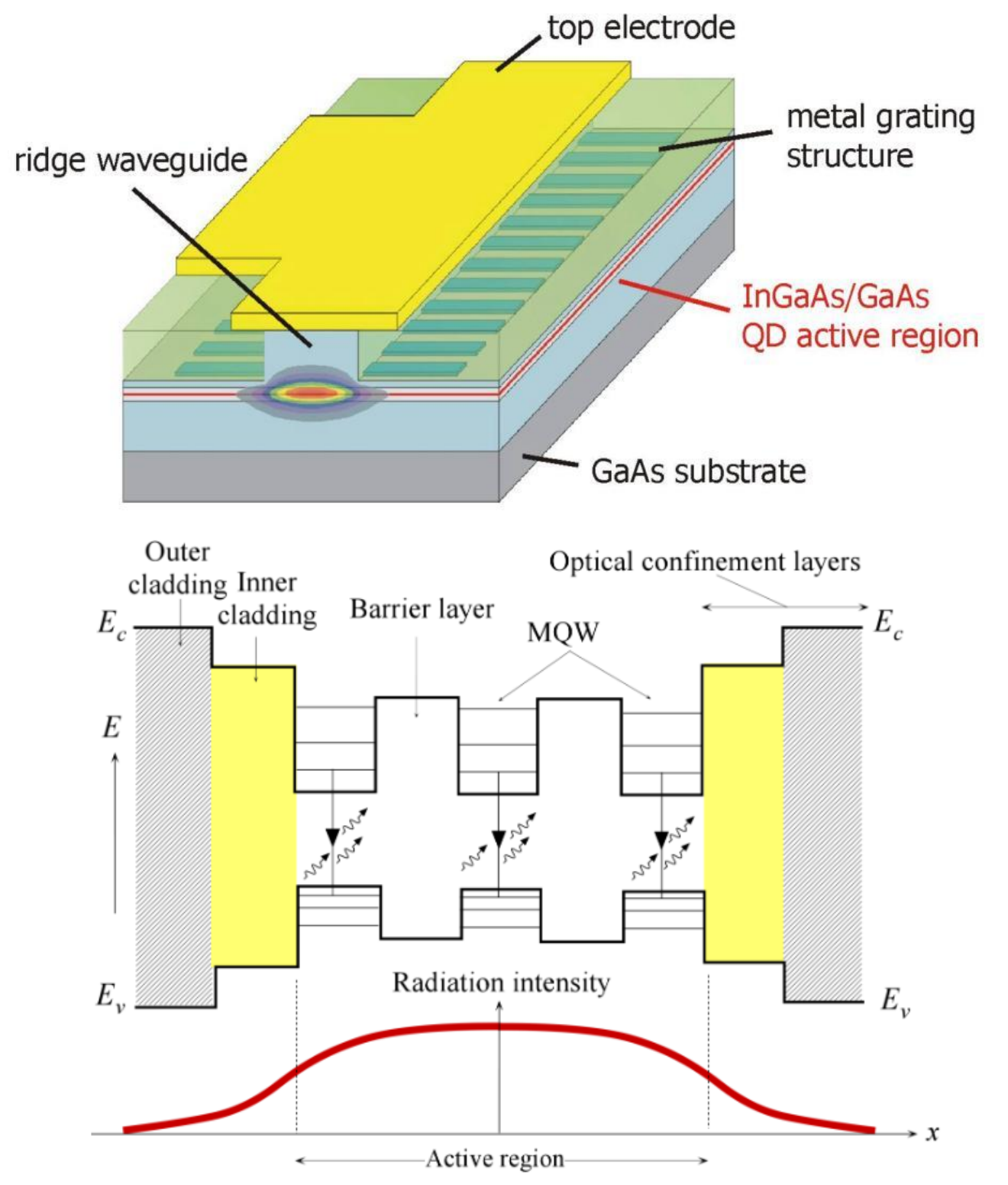
Abstract

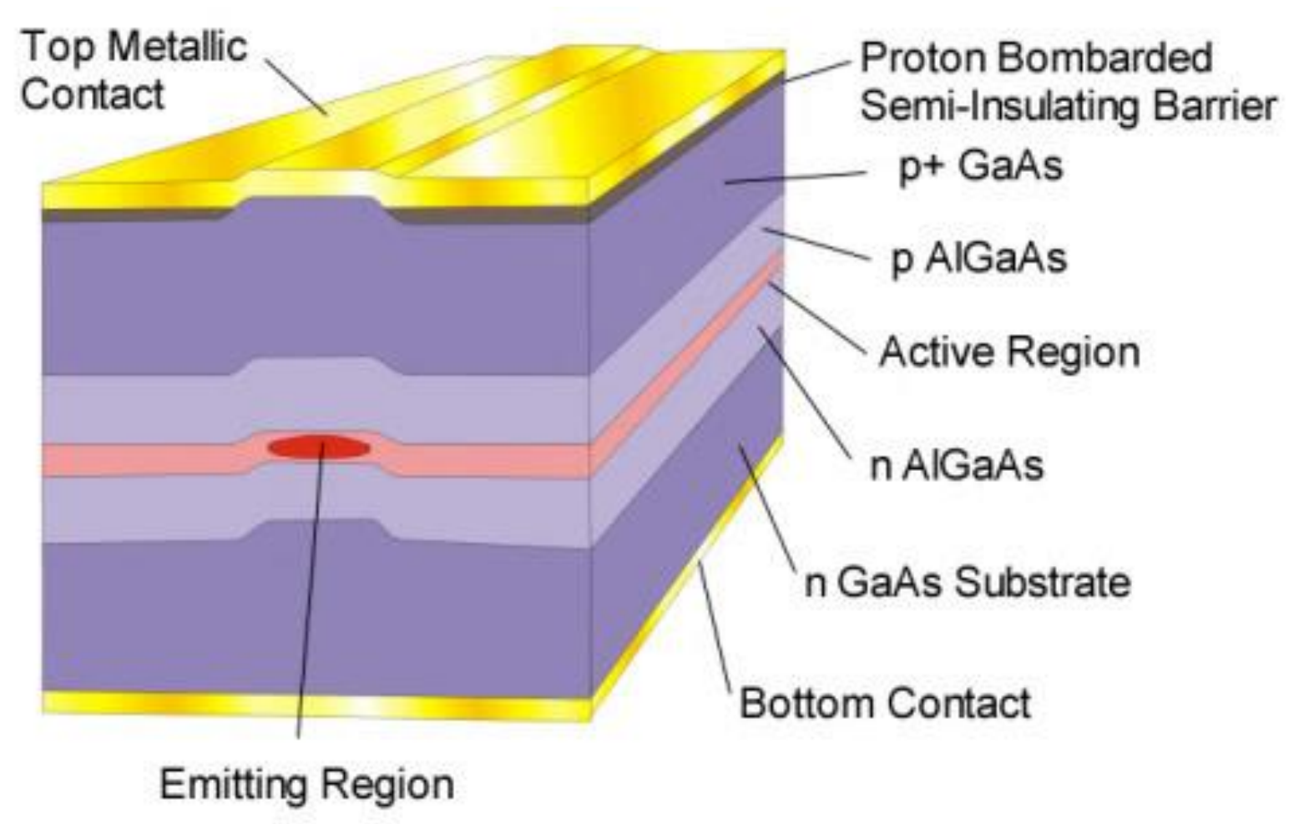
Laser diode characterization is necessary to determine electrical and optical properties of the diode. Here, we present optoelectronic characterization of several laser diodes, including current-voltage (IV), light-current-voltage (LIV), and emission spectra measurements as well as corresponding parameters such as threshold current, turn-on voltage, FWHM, and peak wavelength at various temperatures on continuous wave (cw) mode. Measurements were taken of a Fabry Perot Gallium Arsenide (GaAs) laser die and well as a Fabry Perot and distributed feedback (DFB) Indium Phosphide (InP) laser die. Additionally, we demonstrate a method for using silver epoxy to bond micron scale laser diodes to silicon dies and compare behavior before and after bonding.

Laser Dies



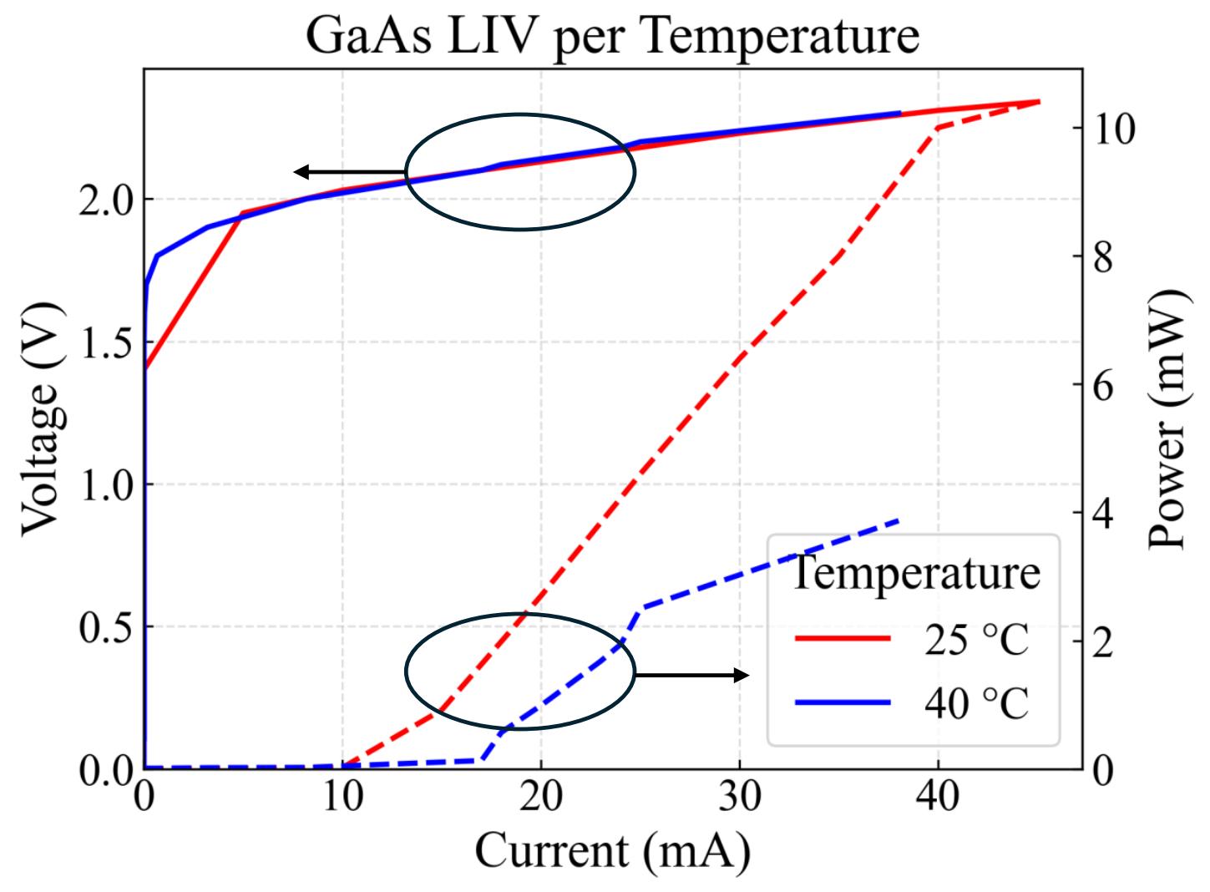
Introduction

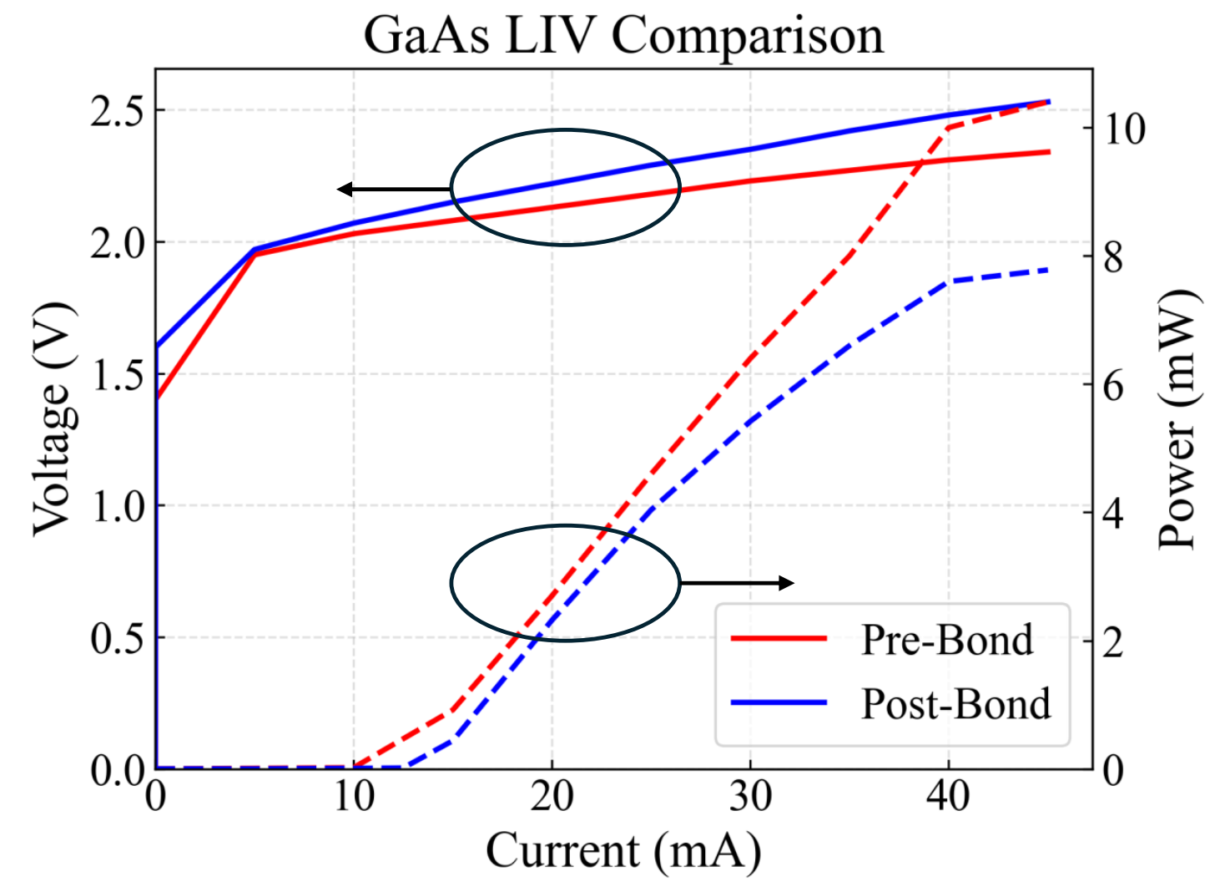


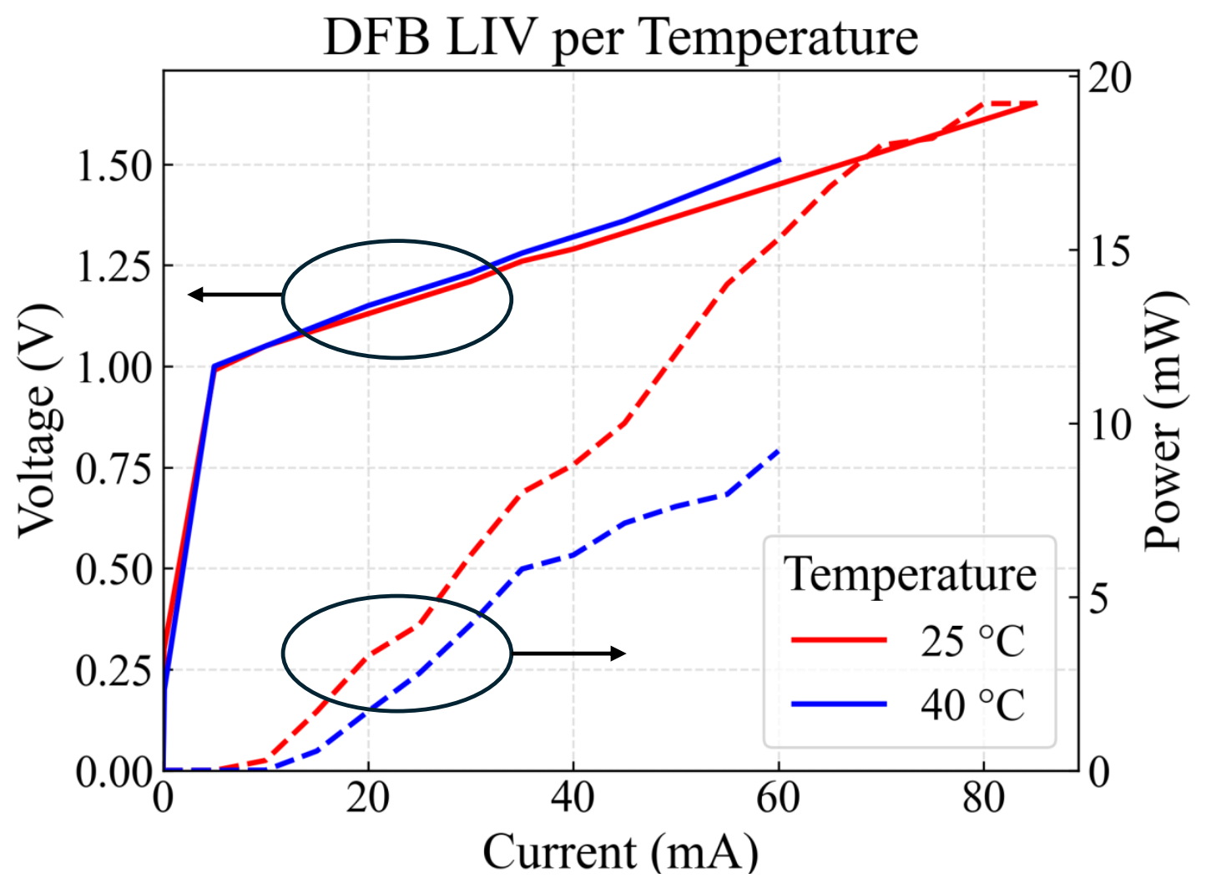


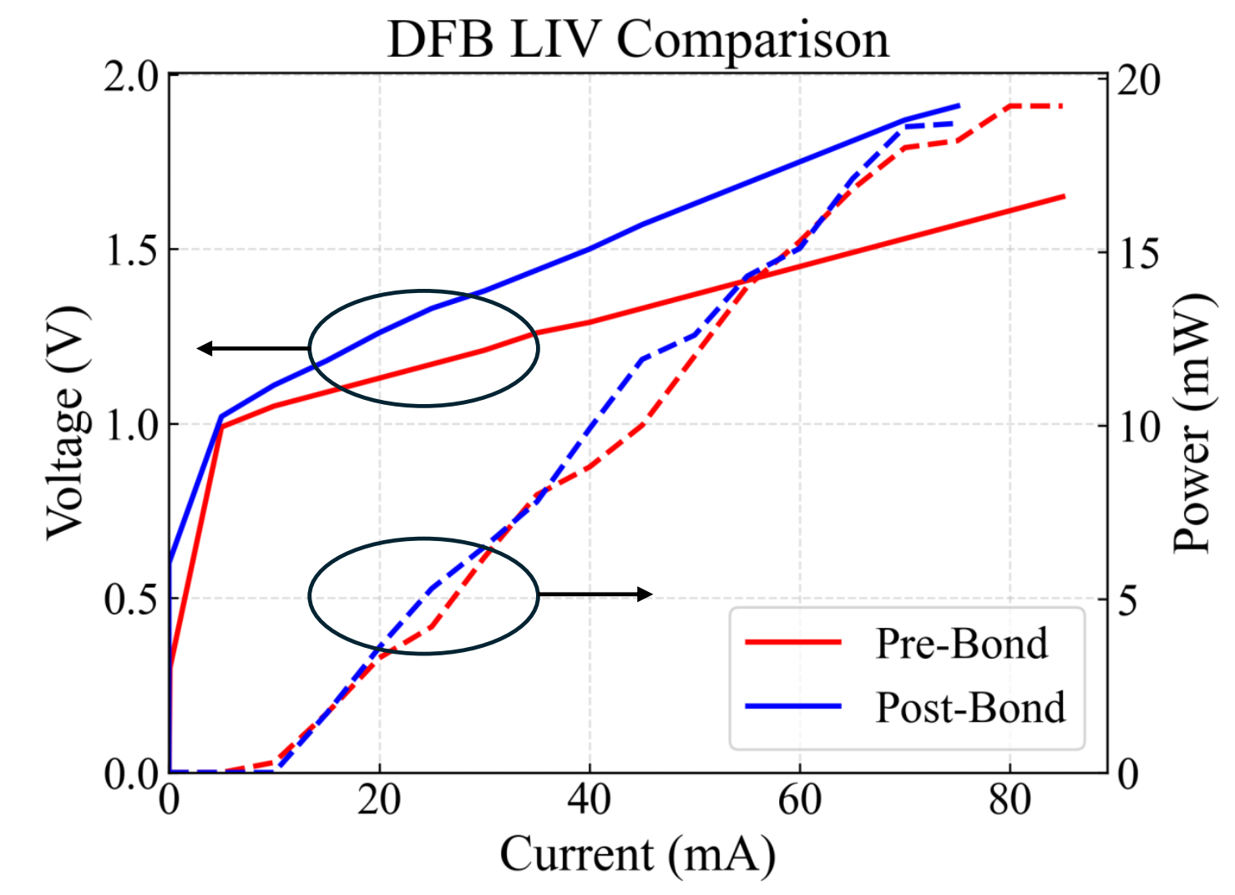
Semiconductor lasers or laser diodes are essential in many applications where compact, coherent, and efficient light sources are needed, such as in telecom, datacom, sensing, and especially LiDAR systems. A major benefit to these laser diodes is the ability to integrate them with metasurfaces or photonic integrated circuit (PIC) components through hybrid or heterogeneous integration. III-V materials like Gallium Arsenide (GaAs) and Indium Phosphide (InP) have direct bandgaps, and therefore high efficiency. Structures such as quantum wells, distributed feedback (DFB) gratings, and Fabry Perot cavities can be consistently fabricated using modern methods like molecular beam epitaxy (MBE) or metal organic chemical vapor deposition (MOCVD). The most common method for integrating III-V laser dies with silicon is using a die bonding machine. For small laser dies like ours that are around 250 microns in length and width, the pick and place technique and epoxy can be used to bond the laser dies. Reliable integration of III-V light sources remains a key challenge.

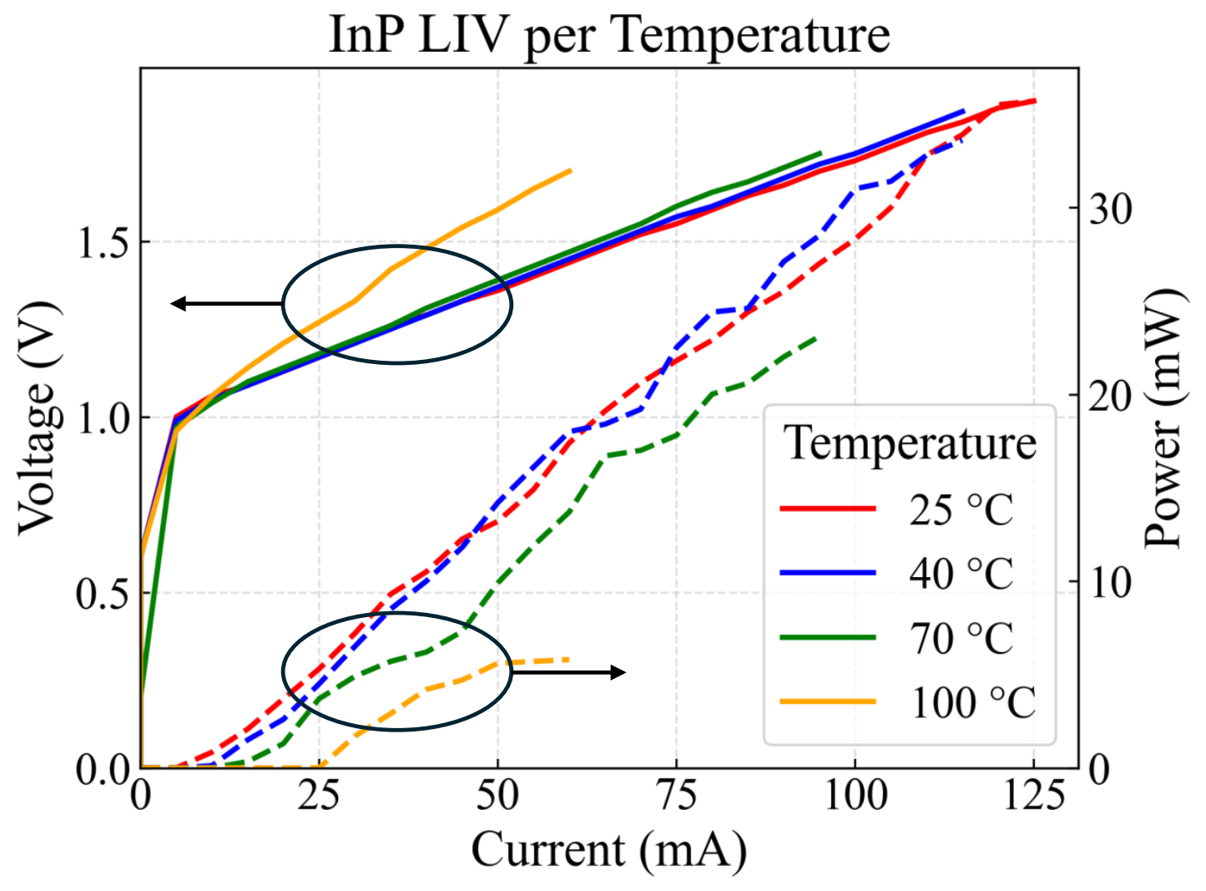
Data and Results

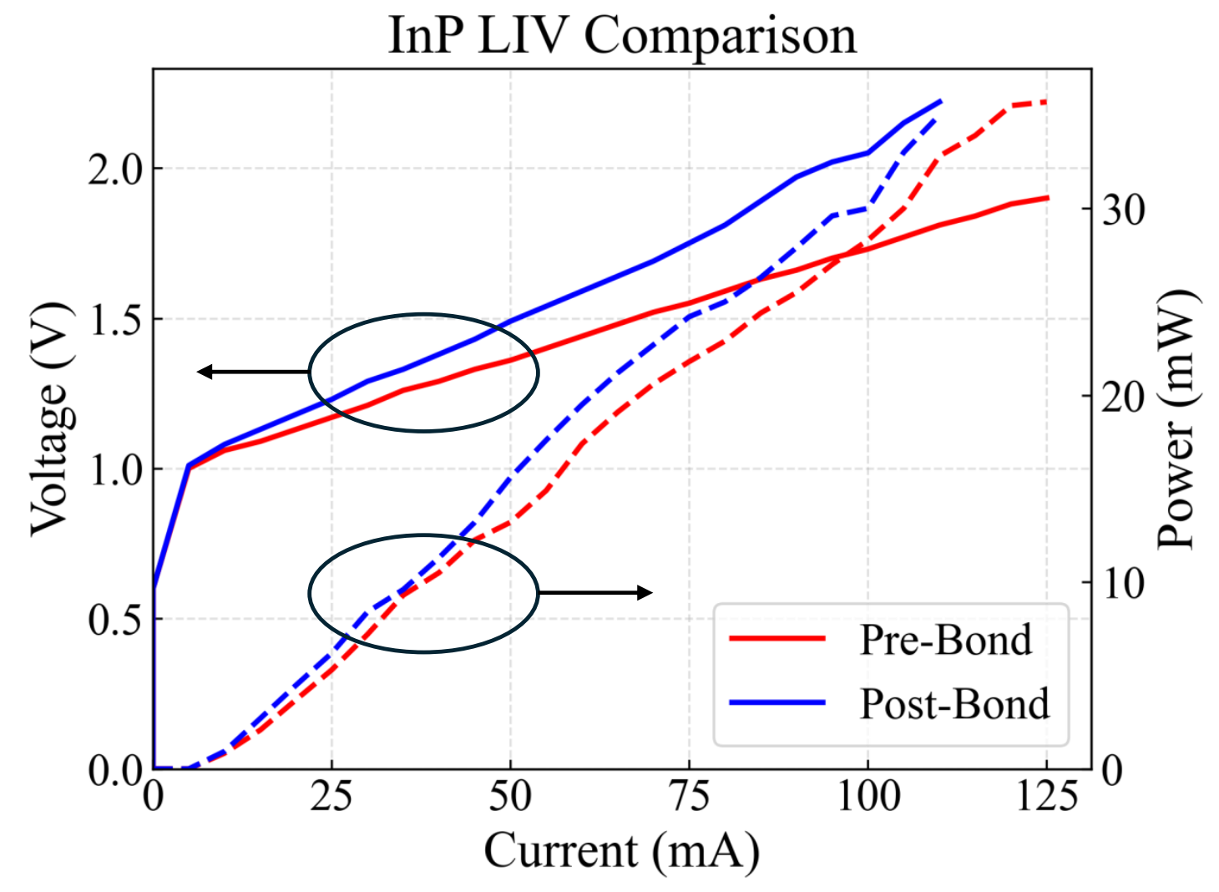




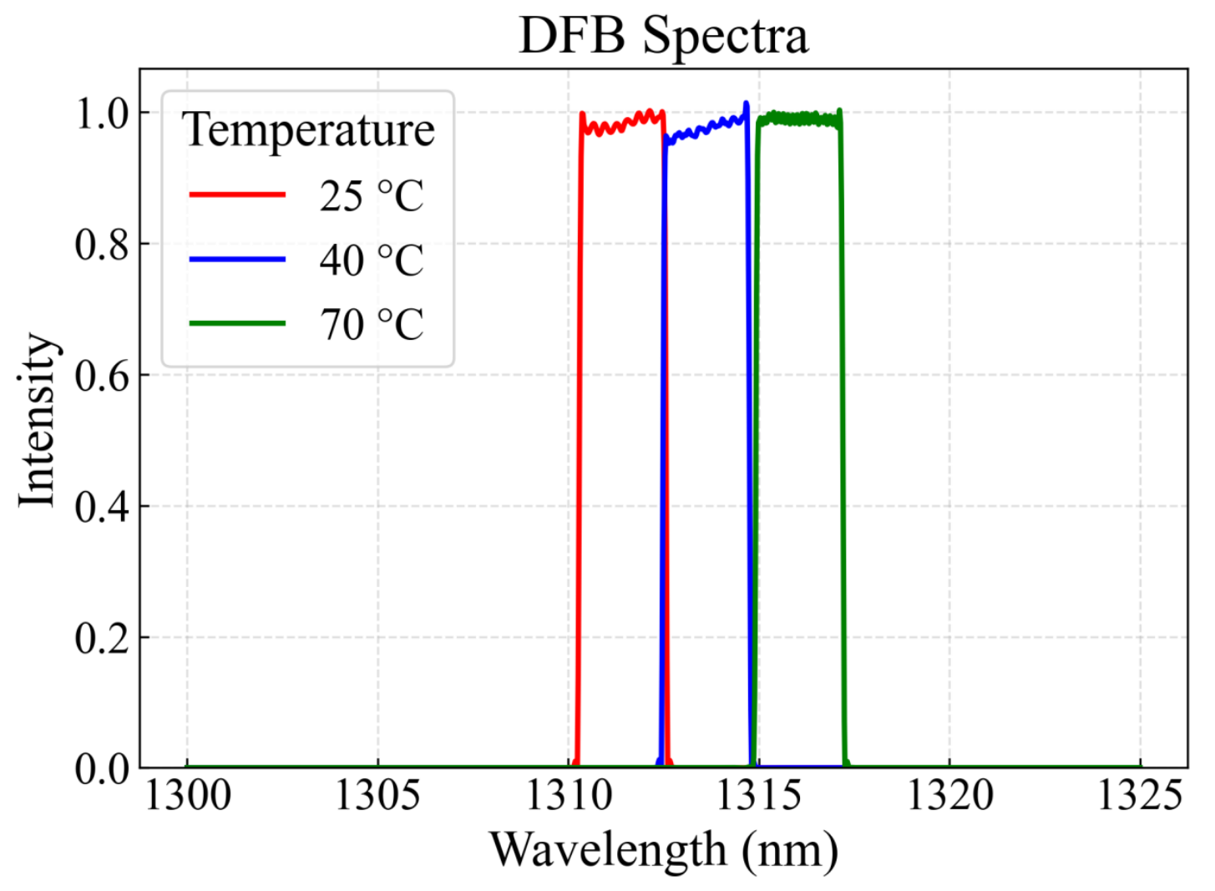


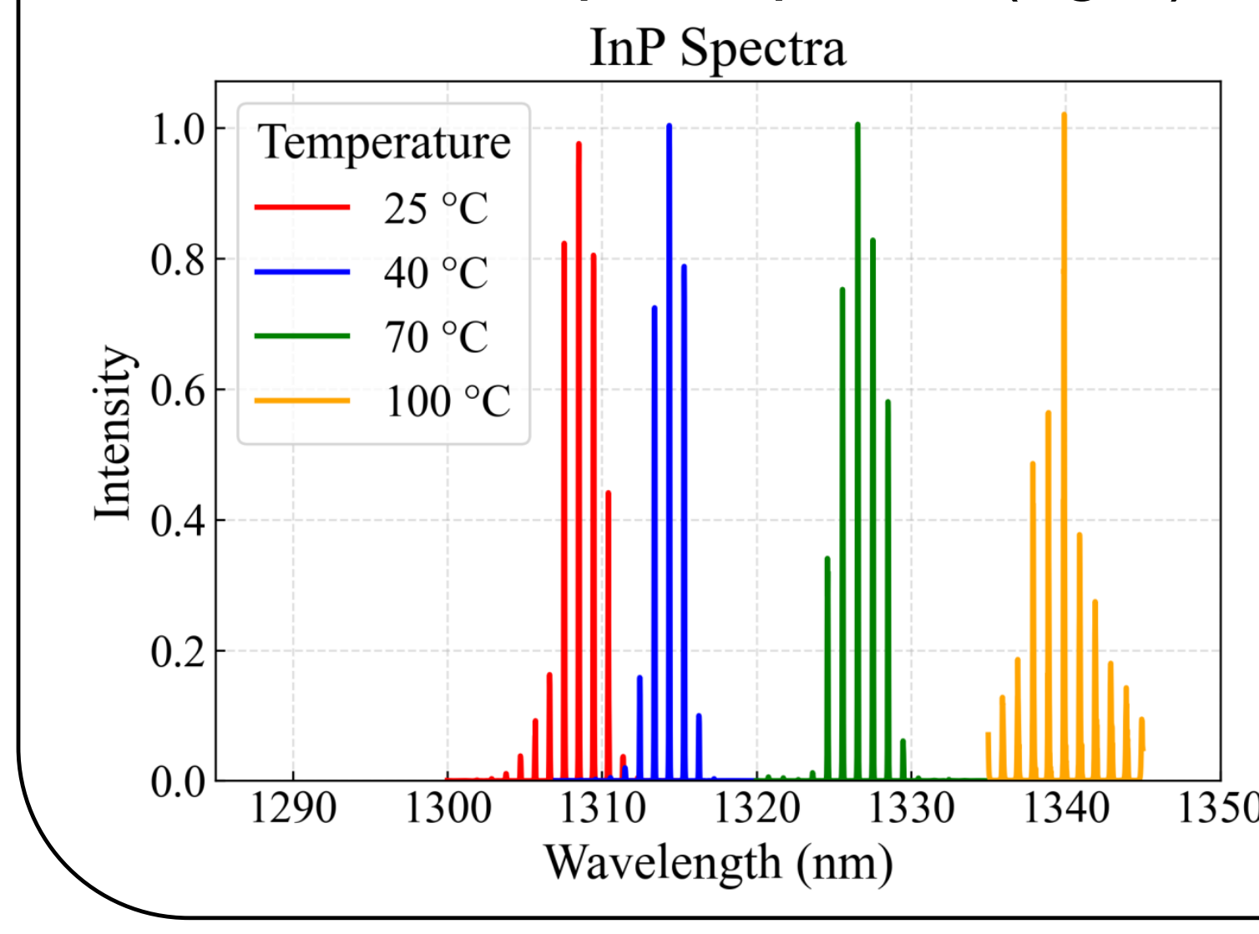


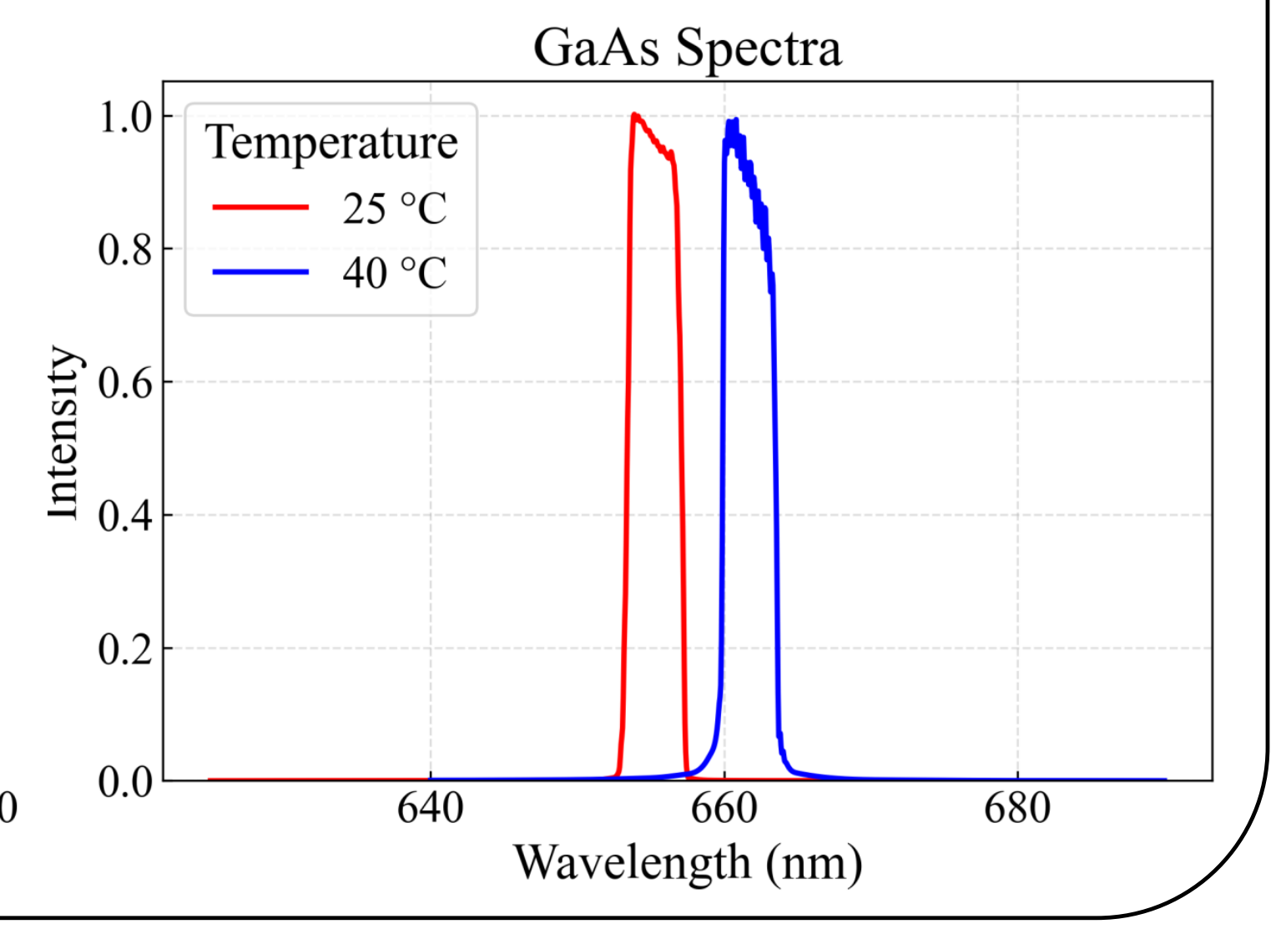




Above are each die's LIV curves per temperature and LIV comparison before and after bonding. To the right and below are the optical spectra results. All results were obtained on continuous wave mode. In LIV graphs, solid curves show voltage (left axis), while dashed curves show optical power (right).



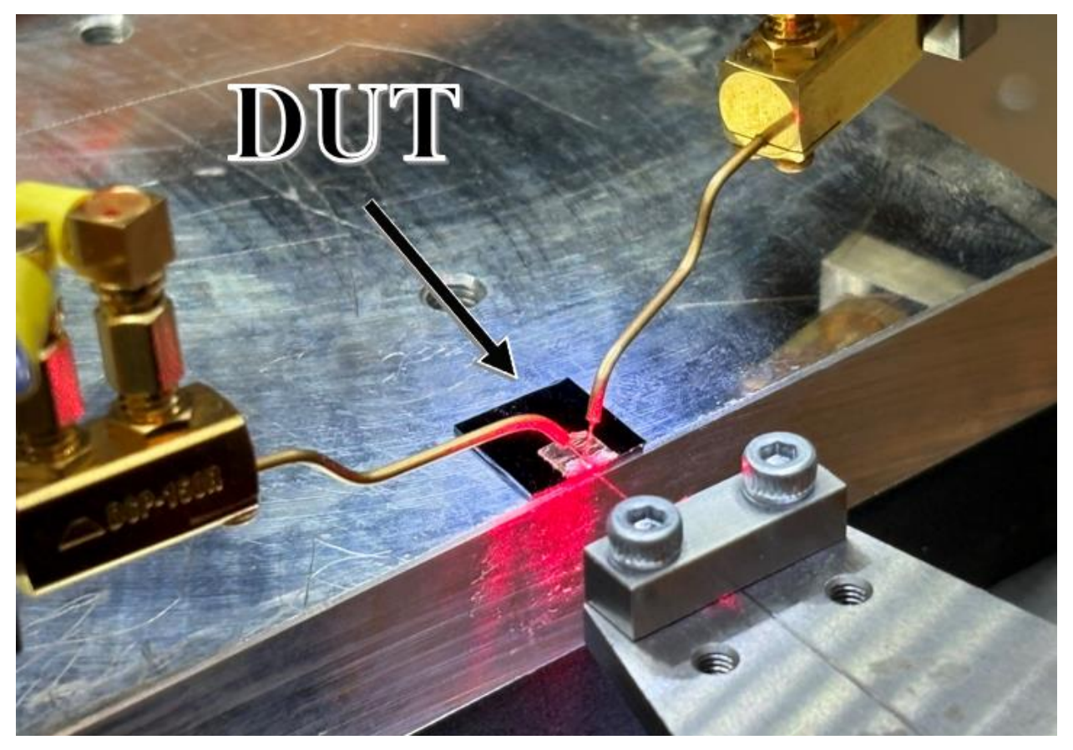




Key Results

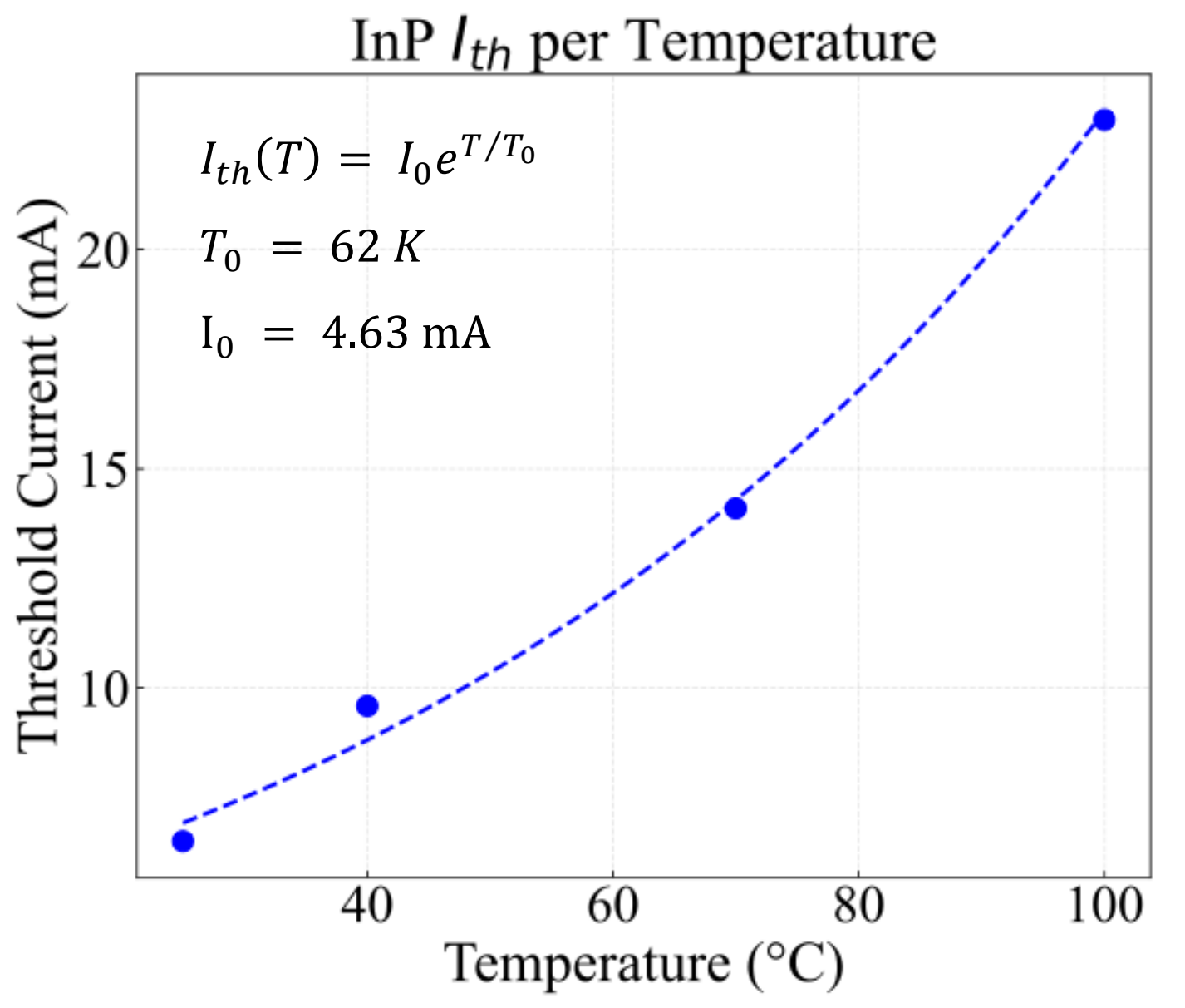
GaAs, DFB, and InP laser diodes' IV characteristics stay consistent. Turn on voltage remains consistent. Threshold current increases exponentially with temperature while emission wavelength increases linearly with temperature. The DFB laser diodes show much lower linewidth than the Fabry Perot laser diodes. Silver Epoxy provides conduction without altering LIV performance.

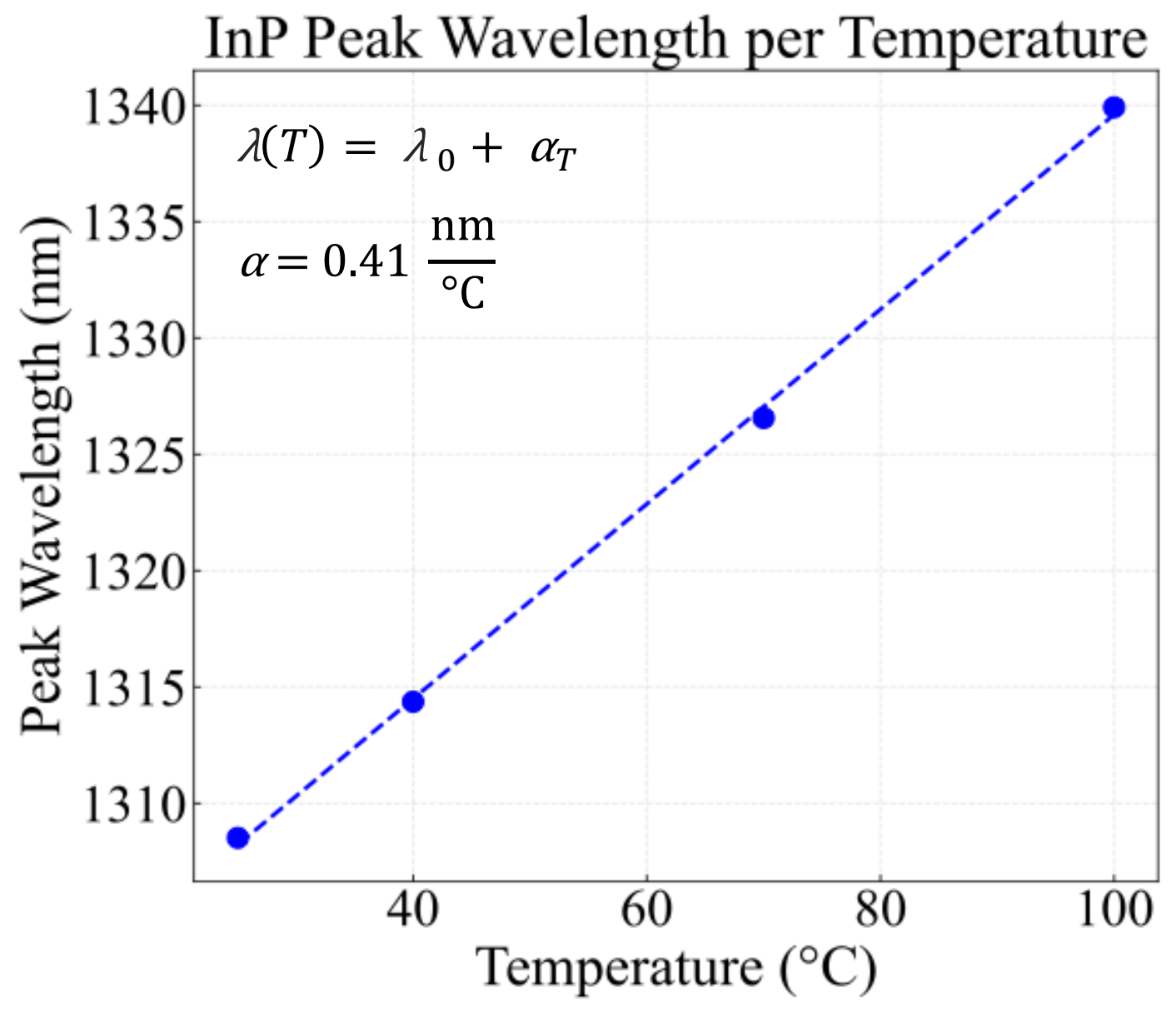
Experiment and Methods



A Keithley 2636B Sourcemeter was used for current-voltage (IV) measurements. The device under test sits on a thermoelectric cooler (TEC) to control the temperature. For light-current-voltage (LIV) and intensity vs wavelength testing, a lensed fiber is coupled to the device's optical output. This fiber is coupled to a detector or a Yokogawa Optical Spectrum Analyzer (OSA). The bonded device consists of a laser die bonded to copper tape with silver epoxy atop a silicon die. To achieve this, a wafer was diced into 0.8 mm by 0.8 mm dies, a piece of copper tape was laid on top, and was covered by a thin layer of epoxy which the die was placed on. Epoxy was cured at 100° C for 30 minutes.

Results and Analysis





Laser Diode	GaAs		DFB			InP		
Temperature (C)	25	40	25	40	70	25	40	70
Turn On Voltage (V)	1.8	1.8	0.9	0.9	-	0.95	0.95	0.95
Threshold Current (mA)	11.3	16.2	5.7	8.6	-	6.5	9.59	14.1
Peak Wavelength (nm)	653.9	660.9	1312.1	1314.7	1317.1	1308.5	1314.4	1326.6
FWHM (nm)	3.7	3.6	2.3	2.3	2.3	2	2	3
Efficiency Before (%)	9.8	4.4	14.9	10.2	-	15.7	15.6	13.9
Efficiency After (%)	5.6	-	14.2	-	-	14.3	-	-

The laser diodes' IV characteristics stayed mostly consistent. Efficiency dropped significantly for GaAs and DFB laser diodes and optical output was negligible after 40 °C. Interestingly, the InP laser diode displayed consistent performance up to 70 °C. Heat can change the properties of the laser diodes' materials, leading to increased wavelength or lower energy photons as temperature increase. Some laser dies have higher efficiency off of peak power, efficiencies listed here are at peak power.

Conclusion

GaAs and InP laser diodes were characterized and compared. The infrared laser dies displayed high efficiency after bonding. Our next steps for this research is to optimize the amount of epoxy used to limit the die's movement in the drying process, install a less noisy TEC, continue threshold current and peak wavelength analysis, and test these diodes' LIV characteristics on pulsed mode.

Acknowledgements

I'd like to thank Dr. Demirbas for her massive help. I'd also like to thank other professors like Dr. Serna and Dr. Deveney for his help and BSU for providing funding for this project.

Contact: b1boucher@student.bridgew.edu